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STUDY OF THE DYNAMICS OF ORBITAL ASSEMBLIES INCLUDING INTERACTIONS WITH GEOMETRICAL APPENDAGES

Contract Number NAS 8-26131

UNIFIED FLEXIBLE SPACECRAFT LOAD PROGRAM
(LOAD)
FINAL REPORT

December 1972
TRW No. 14938-6013-RU-00

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FINAL REPORT

This report was prepared by TRW Systems Group under Contract NAS8-26131 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of Mr. Wayne Holland of the Astronautics Laboratory, George C. Marshall Space Flight Center.

I. INTRODUCTION

The primary objective of the present follow-on to Contract NAS8-26131 is the addition of a dynamic loads computation capability to the Unified Flexible Spacecraft Simulation (UFSS) Program originally developed for the NASA MSFC under the above named contract. This added capability provides a means for determining the internal member loads due to the time-varying external loading conditions experienced by an orbiting spacecraft/cluster.

Consistent with the guidelines used in the development of the original UFSS Program, the dynamic loads computation is completely generalized and applicable to structural components of widely varying configurations.

As described below, the present updated UFSS Program and the newly developed Unified Flexible Spacecraft Load Program (LOAD) completely fulfill all the objectives of the original and follow-on contracts. Following the initial delivery to the MSFC, several efficiency modifications and advanced capabilities were added to the UFSS Program by TRW Systems in the normal course of using the program in-house. These capabilities (to be described in Section IV below) have been included in the present version of the program at no extra cost to the MSFC.

A complete list of final deliverables for the present contract is contained in Section III of this document.

II. GENERAL DESCRIPTION OF THE DYNAMIC LOAD CALCULATION CAPABILITY

The UFSS Program is a general purpose digital computer program designed to simulate the dynamic response of controlled, multibodied, flexible space vehicles subjected to environmental and operational disturbances. The synthesizing algorithm within UFSSP is based on elimination of the interaction forces and torques between adjacent bodies of the system model. By so doing, the final system of matrix differential equations includes only the unconstrained degrees of freedom of the spacecraft model. This retention of the minimal number of degrees of freedom contributes greatly to reducing the cost of the solution for the dynamic response. However, when the dynamic loads are desired, the

interaction forces and torques, as well as the internal loads within a given flexible body, must be obtained explicitly.

Determination of these loads can be divided into two basic phases. In the first phase, the forces and moments acting at each interconnection between adjacent bodies are calculated within the UFSS Program via information available from the original dynamics subroutines. In the second phase, the mode-acceleration method is utilized to calculate internal loads within any desired member of the structural model for a given terminal flexible body. These internal loads are calculated by a separate, stand-alone program operating upon a special loads history tape generated by the UFSS Program. Thus, if only the interconnection loads are desired, these can be obtained from the UFSS Program time history run itself by merely setting the LOAD option flag to "ON". User information necessary to run the UFSS Program is contained in Reference 1, while details of the equations actually programmed to perform these load calculations are presented in Appendix D of Reference 2. Programming operation of the UFSS Program is contained in Reference 3.

Because of the core storage required to save the necessary input data and the fact that internal load calculations can be performed subsequent to the dynamic simulation of a given system, it was decided that the stand-alone program "LOAD" be generated to calculate the internal loads within a given flexible body instead of calculating them within a new subroutine of UFSSP.

In the UFSS Program, flexible bodies are modeled in the traditional structural dynamics sense as a system of joints (or nodes) which are interconnected by weightless finite element members (e.g., beams, plates...). All masses are lumped at the joints. The orthogonal functions used to describe the spatial deformation of the bodies are normally taken to be the orthonormal cantilever modes produced by a standard structural dynamics program such as NASTRAN, SAMIS, or SMAP. In general, most such programs are based on small deflection theory, using the direct stiffness matrix finite element approach assuming linear stiffnesses. Such an approach allows for the generation of a specific transformation matrix, herein called the load transformation matrix (LTM), by a systematic application of a unit force along each degree of freedom with all other forces set equal

to zero. In particular, such a matrix allows the LOAD Program to calculate internal member forces through the simple matrix multiplication operation:

$$L_M(t) = B_{MQ} \; F_Q(t) \tag{1}$$

In the above equation, each component of $L_M(t)$ represents a specific desired internal member load, B_{MQ} is the LTM and $F_Q(t)$ is the applied force vector. Specifically, B_{MQ} contains, as rows, coefficients for each degree of freedom relating the desired load to a unit force applied successively along each translational degree of freedom of the structure (assumed to be three times the number of joints in the UFSSP model since only the modal translations are used to describe deformations), and the ordering of the columns must be identical to the degree of freedom ordering within the mode shapes. The applied force vector, $F_Q(t)$, contains both the externally applied forces (environmental forces, control forces...) and the inertial (d' Alembert) forces associated with the inertial velocity and acceleration of each joint. For the present initial implementation of the LOAD Program, the allowable externally applied forces acting on the flexible bodies can be added at any future time if a specific application calls for their inclusion). There are no restrictions on the disturbance forces and/or torques acting on the rigid bodies of the system model.

Figure 1 presents an overview on the program interfaces. As seen from Equation (1), only two basic quantities are required for the loads computation. The first quantity, B_{MQ} , is obtained from any suitable structural dynamics program; the second quantity, $F_Q(t)$, is obtained from the UFSS Program via a special history tape.

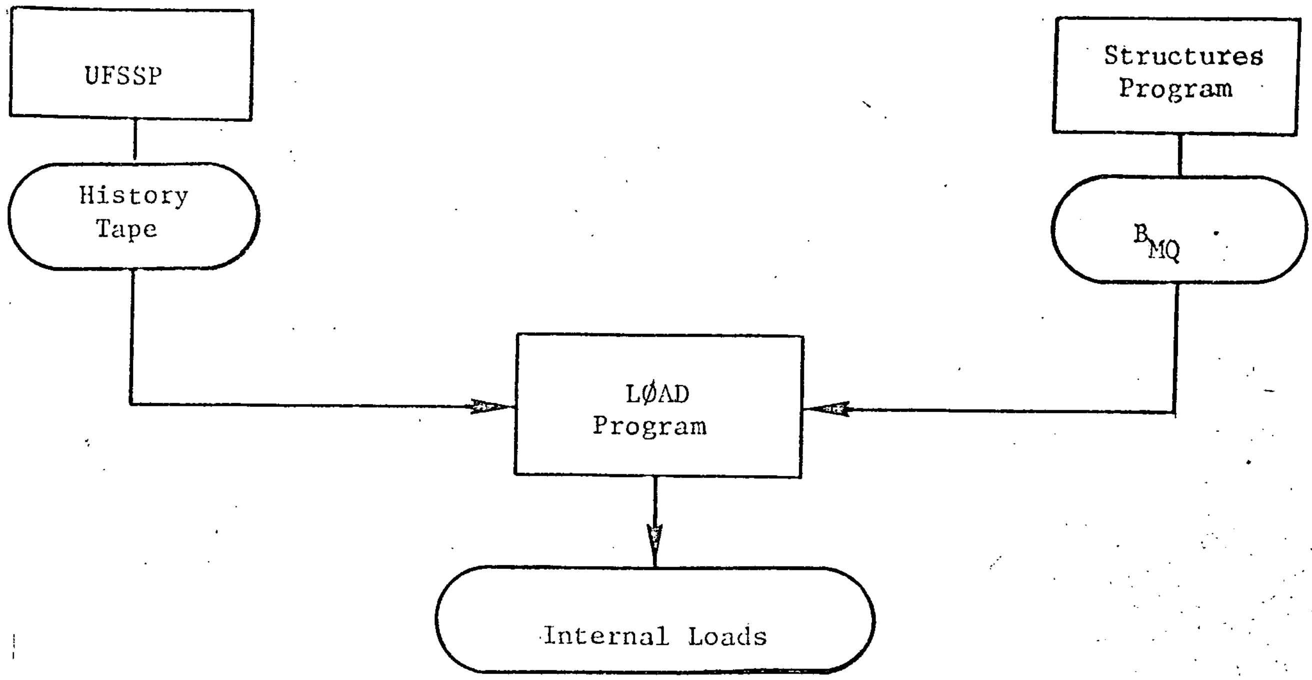

Figure 1. Basic Interfaces for Internal Load Calculations

User information necessary to run the LOAD Program is contained in Reference 4, while details of the equations actually programmed to perform the LOAD calculations are presented in Appendix D of Reference 2. Since the LTM must be obtained from an independent program of the user's choice, descriptions of its formulation and format are contained in Section III and Appendix A of Reference 4.

III. LIST OF DELIVERABLES UNDER THE PRESENT CONTRACT

The following items constitute the final deliverables for the present follow-on to Contract NAS 8-26131:

1. A PCF tape containing the source and object decks for the updated UFSS Program suitable for operation on the MSFC Univac 1108 EXEC II computing system.
2. A PCF tape containing the source and object decks for the LOAD Program suitable for operation on the MSFC Univac 1108 EXEC II computing system.
3. Input data decks necessary to run the UFSS Program "user manual test case" plus print-out of the test case results.
4. Input data decks and a copy of the UFSSP history tape necessary to run the LOAD Program "user and operation manual test case" plus print-out of the test case results.
5. Nine (9) copies of this report and each of the documents listed in the References section of this report.

IV. ADDITIONAL PROGRAM FEATURES INCLUDED IN THE UFSS PROGRAM

In the course of using the UFSS Program in-house, the following features have been incorporated into the UFSS Program and are hereby included gratis in the present delivery of the program to the MSFC:

1. In addition to the original capability of inputting the flexible structures data via magnetic tape, a simplified format has been included for inputting this data via a card deck or a disk/drum file.
2. A "high spin" capability has been included in the program. The dynamics of rapidly spinning flexible bodies (modeled as either space curves or flat plates) is now handled automatically by an internal addition of a modified displacement function (curvature shortening effect) for each flexible body; thus, the centrifugal stiffening effect as well as all other acceleration effects are now included in the flexible body dynamics.

3. In the initial UFSS Program, Body 1 kinematics were obtained by direct integration of its nine element direction cosine matrix. In the present version, this method has been replaced by a much more efficient and accurate calculation of the direction cosine matrix via integration of four "Euler parameters".

V. REFERENCES

1. Ness, D. J., Hull, G. E. and Farrenkopf, R. L., "Unified Flexible Spacecraft Simulation Program (UFSSP) Users Manual," TRW No. 14938-6009-RU-00, December 1972.

2. Ness, D. J., "Unified Flexible Spacecraft Simulation Program (UFSSP) Methodology Report," TRW No. 14938-6010-RU-00, December 1972.

3. Hull, G. E., and Ness, D. J., "Unified Flexible Spacecraft Simulation Program (UFSSP) Operation Manual," TRW No. 14938-6011-RU-00, December 1972.

4. Hull, G. E., and Ness, D. J., "Unified Flexible Spacecraft Load Program (LOAD) Users and Operation Manual," TRW No. 14938-6012-RU-00, December 1972.

STUDY OF THE DYNAMICS OF ORBITAL ASSEMBLIES
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Contract No. NAS 8-26131

UNIFIED FLEXIBLE SPACECRAFT LOAD PROGRAM (LOAD)

USER'S AND OPERATION MANUAL

December, 1972
TRW No. 14938-6012-RU-00

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INTRODUCTION

The LOAD Program is a digital computer program designed to calculate internal loads within the flexible bodies of any model admissible to the Unified Flexible Spacecraft Simulation (UFSS) Program.

As described in [1]*, the UFSS Program is a general purpose digital computer program designed to simulate the dynamic response of controlled, multibodied, flexible space vehicles subjected to environmental and operational disturbances. The synthesizing algorithm within UFSSP is based on elimination of the interaction forces and torques between adjacent bodies of the system model. By so doing, the final system of matrix differential equations includes only the unconstrained degrees of freedom of the spacecraft model. This retention of the minimal number of degrees of freedom contributes greatly to reducing the cost of the solution for the dynamic response. However, when the dynamic loads are desired, the interaction forces and torques, as well as the internal loads within a given flexible body, must be obtained explicitly.

The forces and moments acting at each interconnection between adjacent bodies are calculated within the UFSS Program itself via information available from the original dynamics subroutines. In the LOAD program described herein, the mode-acceleration method is utilized to calculate internal loads at any desired node point within a given terminal flexible body. These internal loads are calculated by suitably operating upon a special loads history tape generated by the UFSS Program.

This present document contains all the necessary information for using the LOAD program. For details of the equations utilized in the programming, the user is referred to Appendix D of the UFSSP Methodology Report [2].

Section I herein contains a general description of the program and Section II lists the principal capabilities. Section III presents a complete listing and description of all input data quantities while Section IV contains additional input information. Section V details the available output from the program and the use of the error messages. Section VI presents sample case runs including output prints and plots.

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*numbers in brackets denote references.

Sections VII through XI constitute the Operation Manual for the LOAD program. Section VII contains the software/hardware requirements and Section VIII presents the overall deck setup. Section IX details the tape/disk/drum usage while Section X contains load maps for both the CDC 6500 and the Univac 1108. Finally, Section XI presents an overall block diagram of the LOAD program, while Appendix A contains a description of the required load transformation matrix (LTM).

I GENERAL DESCRIPTION OF THE LOAD PROGRAM

In the UFSS Program, flexible bodies are modeled in the traditional structural dynamics sense as a system of joints (or nodes) which are interconnected by weightless finite element members (e.g., beams, plates...). All masses are lumped at the joints. The orthogonal functions used to describe the spatial deformation of the bodies are normally taken to be the orthonormal cantilever modes produced by a standard structural dynamics program such as NASTRAN, SAMIS, or SMAP. In general, most such programs are based on small deflection theory, using the direct stiffness matrix finite element approach assuming linear stiffnesses. Such an approach allows for the generation of a specific transformation matrix, herein called the load transformation matrix (LTM), by a systematic application of a unit force along each degree of freedom with all other forces set equal to zero. In particular, such a matrix allows internal member forces to be calculated through the simple matrix multiplication operation.

$$L_M(t) = B_{MQ} \; F_Q(t) \tag{1}$$

In the above equation, each component of $L_M(t)$ represents a specific desired internal member load, B_{MQ} is the LTM and $F_Q(t)$ is the applied force vector. Specifically, B_{MQ} contains, as rows, coefficients for each degree of freedom relating the desired load to a unit force applied successively along each translational degree of freedom of the structure (assumed to be three times the number of joints in the UFSSP model since only the modal translations are used to describe deformations), and the ordering of the columns must be identical to the degree of freedom ordering within the mode shapes. The applied force vector, $F_Q(t)$, contains both the externally applied forces (environmental forces, control forces...) and the inertial (d'Alembert) forces associated with the inertial velocity and acceleration of each joint.

Because of the core storage required to save the LTM and the fact that internal load calculations can be performed subsequent to the dynamic simulation of a given system, it was decided that the present stand-alone program "LØAD" be generated to calculate the internal loads within a given

flexible body instead of calculating them within a new subroutine of UFSSP. Figure 1 presents an overview of the program interfaces. As seen from Equation (1), only two basic quantities are required for the loads computation. The first quantity, B_{MQ}, is obtained from a structural dynamics program; the second quantity, $F_Q(t)$, is obtained from the UFSS Program via a special history tape.

As previously mentioned, the row index, M, of B_{MQ} runs from one to A, where A is the total number of internal loads to be calculated; the column index, Q, runs from one to 3N, where N is the total number of joints in the structural dynamics model of the given flexible body, as input to UFSSP. Additional description of the LTM is contained in the description of the Sample Case presented in Section VI of this document and in Appendix A.

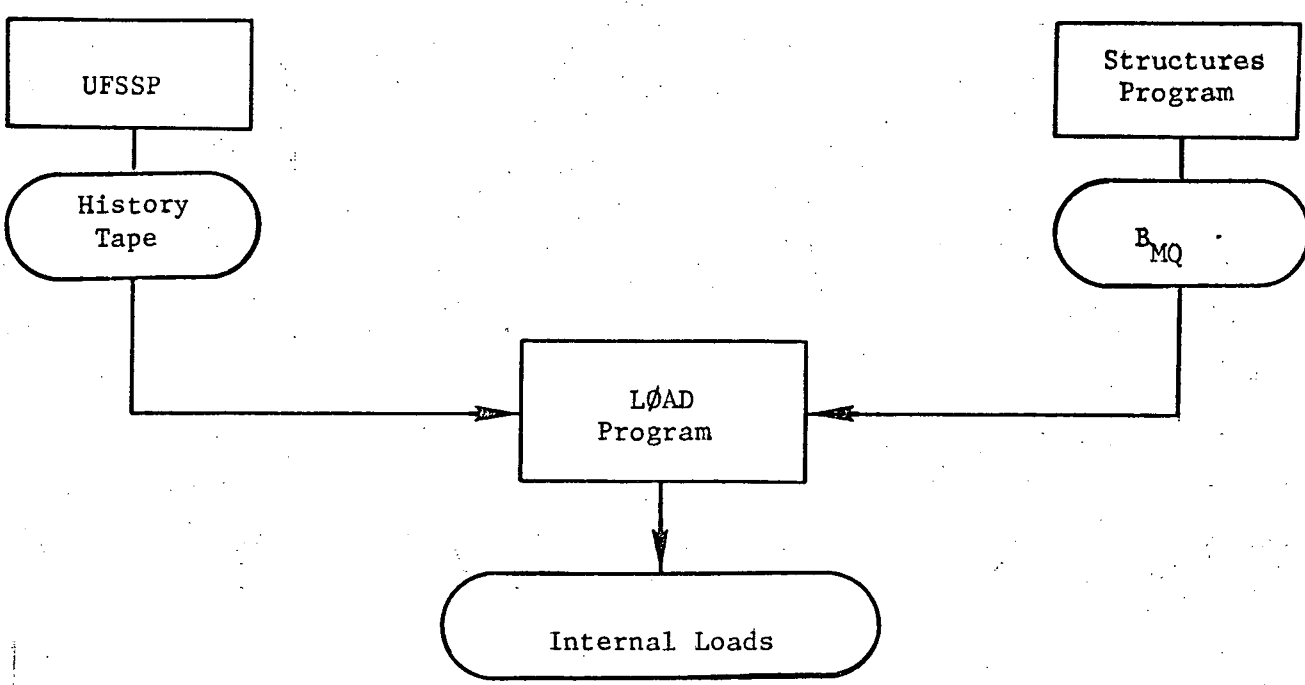


Figure 1. Basic Interfaces for Internal Load Calculations

The LOAD Program calculates internal loads for one flexible body at a time; thus, a single LTM is input for each run. The input LTM is matched to the appropriate flexible body through the input quantity NØBØD, and the LTM data can be input either as a card deck or as a tape (or disk) file.

The input LTM can contain up to 72 rows (each row corresponding to a desired internal load), and any subset of these rows can be selected for computation on a given run through input specification via the MSELEC array.

Loads can be calculated for every time point on the UFSS history tape or only for specific time intervals. Through the input array STIM_n_, the user specifies both the time intervals for calculation and the "sampling rate" at which the calculations are performed. At each time point for which loads are calculated, all loads are written on a history tape for later printing and/or plotting (no printing or plotting option is incorporated within the LOAD program itself).

As the values of the maximum and minimum for each load are of primary interest, the standard output of the LOAD Program consists of an output print of these maximum and minimum values for each load, the time at which they occurred, and the values of all the loads at each of these critical times.

II. PROGRAM CAPABILITIES

A. This program will process one case per job. This means that the loads will be computed for one body at a time.

B. Plotting of Data on the history tape cannot be done in the same job. The TRW utility program PLØT8 can be used to plot the data at a later time.

C. There can be a maximum of 4000 data time points on the output history tape.

D. There can be a maximum of 72 rows of the B^j_{MQ} matrix read in core.

III. LIST OF INPUT DATA ON CARDS

The Namelist data input format is used for all card input except for the header. See Section IVB for instructions on how to input certain data items.

A. DEFINITION OF INPUT DATA ON CARDS

Program Input Name	Dimension	Nominal Value	Data Description
NØCASE	1	--	8 digit case no. to identify the results of this job.
NØBØD	1	0	Body no. j identifying the body within the model processed by UFSSP.
INPTRN	1	25	Unit no. for the input of the card data for the loads transformation matrix, =5 - card read; =25 - file on disk or tape.
MSELEC	2 x 50	All M rows will be processed	B^j_{MQ} row selector tables. There is a possibility of 50 from-to entry pairs. The column represents pair no. Row 1 is the "from" row no. and row 2 is the "to" row no. Example: MSELEC(1,4) =7, 10 means select 7th through 10th rows of B^j_{MQ} matrix from loads transformation file as the 4^{th} from-to entry pair.
HISCSE	1	--	Gives the case no. of the UFSSP history tape.
STIM01-STIM10	3	0	A set of up to 10 different time periods and data selection frequencies used to select time history data from the UFSSP history tape. Example: STIM03(1)=.05, 1.0, 2 means starting at or after time =.05 sec. and ending at or before time =1 sec., select data for every other time point from the tape.
INPRNT	1	≠0	Print input card data option flag, = 0 - no; ≠0 - yes.

IV. INPUT DATA SET DESCRIPTION

A. SOURCES OF DATA OTHER THAN NAMELIST INPUT

1. UFSSP History Tape

This tape is generated by the UFSSP program. It contains structures data and the necessary time history data to compute internal loads. See the UFSSP User's Manual Appendices A-D for the file format and Section IVC.5. for contents of a data record.

2. Loads Transformation Matrix Data (B^j_{MQ})

This input data is submitted either via the card reader or a BCD card image file on disk or tape. This data is generated by the LTMP program (TRW) or keypunched from data load sheets.

Format:

The first card contains the number of rows and columns of the B^j_{MQ} matrix which is on the cards that follow. The last data card is followed by an end of file mark. All cards contain a four digit sequence number in c.c. 77-80 starting with 0001 and increasing by 1's.

Card 1: Header

C.C. 1-3 "M" - No. of rows in B^j_{MQ} matrix

C.C. 4-6 "Q" - No. of columns in B^j_{MQ} matrix ≡ 3*NJTS.

Card 2 - Card n: B^j_{MQ} Matrix

There are up to 5 elements per card

C.C. 1-13 Field 1; C.C. 14-26 Field 2

C.C. 27-39 Field 3; C.C. 40-52 Field 4

C.C. 53-65 Field 5

Each data field will be of the form: ±X.XXXXXXE±YY

The matrix is on the cards by rows so that all columns for one row will come in before the next row is read. Each row starts on a new card.

B. RULES FOR INPUTTING DATA ON CARDS

1. General

a. Floating Point Numbers

$\pm$XXXXX.X, $\pm$X.XXXXXXE$\pm$YY and XXXX are all valid ways of inputting floating point numbers. A maximum of 8 significant digits is allowed.

b. Fixed Point Numbers

$\pm$XXXXX; up to 10 digits are allowed with no decimal point.

c. Omitted Data

Except for data with nominal values and the header which is stored as blanks, the missing items will be set to zero.

d. Namelist Rules

The rules for entering data under the Namelist input routine are in effect. See CDC FORTRAN Manual, pages 10.7-10.8 for details. The Namelist name is $LØAD.

2. How to Enter Specific Data Items

a. Head

This data set is entered starting in card column 1 and the first 42 characters will be picked up. This card must be the first one in the deck just prior to the Namelist data set.

b. MSELEC

The total number of rows selected must be ≤ 72. The "from" value must be ≤ to the "to" value of each set. The current "from" value must be greater than the previous "to". The first 0 entry terminates the data set.

c. INPTRN

The only valid entries are 5 or 25. 5 - means the data for B^{j}_{MQ} will come via the card reader and 25 - means the data will be on file = TAPE25.

d. NØBØD

Care must be taken to make sure the entry j is between 1 and NB, where NB is the number of bodies in the model processed in UFSSP. j must be a flexible body with non-zero flexible degrees of freedom. This quantity must be input.

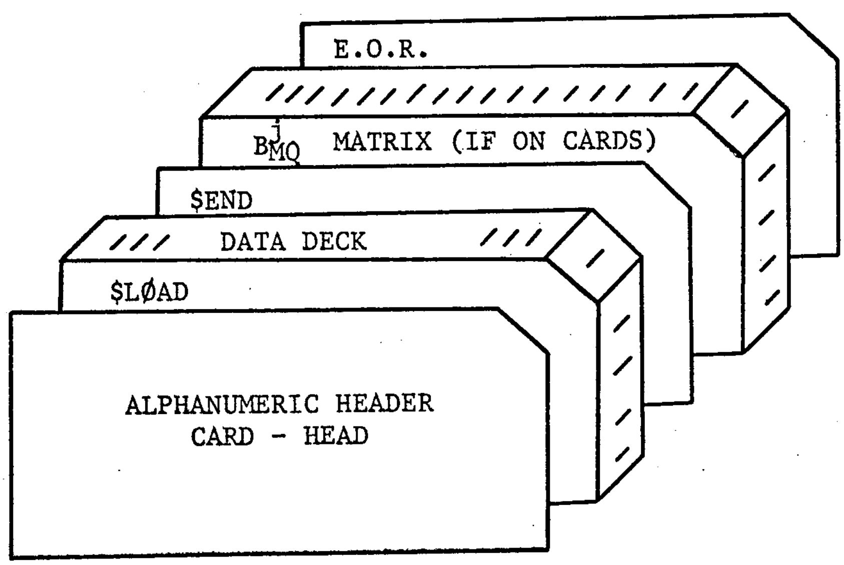
e. STIMn (01 ≤ n ≤ 10)

The current "from" value must be ≥ to the previous "to". The "from" value must be ≤ to the "to" value of each set.

f. HISCSE

This number must agree with the case number on the UFSSP history tape that is mounted.

C. SAMPLE DATA DECK SETUP



V. ØUTPUT

A. GENERAL

There is no control on how often data is printed or written on the history tape. It is done for each time point for which there is a calculation. The history tape is always written. The page is restored so that data for an array will not be split between pages. Unless otherwise stated, the format of a floating point number is ±X.XXXXXXE±YY.

B. PRINTED OUTPUT

The following types of print exist:

1. Case header
2. Error print
3. Input data print
4. Summary of L_i^{max} and L_i^{min} - internal loads (maximum and minimum values).

1. Case Header

This header prints at the top of every page with the following format:

HH--42 CHARACTER HEADER--HH CASE NØ__________BØDY_____PAGE_____

2. Error Print

See Section VD. for details on types and formats of output. Error messages for erroneous input data cards print prior to the input data print.

3. Input Data Print

This output data set is printed at the beginning of each case (on option) and includes all input data quantities and arrays as they will be used in the program. All zero values are printed. Even if there are input errors which cause the job to be terminated, this data will be printed.

Format:

a. Floating Point Numbers

±0.XXXXXXXXE±YY; where trailing zeroes are ignored so that the format is variable.

b. Fixed Point Numbers

±XXXX--X; as many positions print out as there are significant digits. Leading zero are ignored.

c. Single Data Items

Each individual named data quantity prints one per line as follows:

INPTRN = 5.

d. Arrays Print as Follows:

MSELEC =

FRØM n_1 TØ n_2 FRØM n_3 TØ n_4 FRØM n_5 TØ n_6 FRØM n_7 TØ n_8 FRØM n_9 TØ n_{10}

FRØM $\longrightarrow$

FRØM n_{i-3} TØ n_{i-2} FRØM n_{i-1} TØ n_i

where $1 \leq i \leq 50$

STIM =

FRØM±X.XXXXXXE±YY TO ±X.XXXXXXE±YY EVERY n

FRØM $\longrightarrow$

FRØM±X.XXXXXXE±YY TØ ±X.XXXXXXXE±YY EVERY n

4. L_i^{max} and L_i^{min} Print

The print format on a page for one L_i^{max} and L_i^{min} is as follows:

MINIMUM LØAD(PØSITION_____) = ±X.XXXXXXE±YY TMIN=X.XX--

LØAD VECTØR FØR MINIMUM

PØS	VALUE	PØS	VALUE	PØS	VALUE
1	±X.XXXXXX±YY	2	±X.XX---	6	±X.XX---
7	±X.XX--		±X.XX---	12	±X.XX---

m ±X.XX---

MAXIMUM LØAD(PØSITION_____) = ±X.XXXXXXE±YY TMAX=X.XX_____

LØAD VECTØR FØR MAXIMUM

PØS	VALUE	PØS	VALUE
1	±X.XXXXXXE±YY	2	±X.XX---

The L_i^{max} and L_i^{min} printout in vector position order $1 \le i \le m$, where $1 \le m \le 72$.

C. HISTORY TAPE

This tape contains the L_m^j vector for each time point processed by this program. This tape cannot be processed as part of the job in which it is created. It is formatted for use by the TRW stand alone version of the PLØT8 program. This program will print the L_m^j or generate a plot tape for plotting on a calcomp plotter. See the PLØT8 writeup for its use and capabilities.

1. Format

I.D. RECORD

HEAD(1-7)	-	"INTERNAL LOADS PROGRAM"
HEAD(8-14)	-	The BCD data from HEAD
HEAD(15-22)	-	Unused
YEAR(1-3)	-	Unused
PLØT5	-	Unused
CPLTV(1-48)	-	Unused
TMØN	-	Unused
TMØFF	-	Unused
NWRDS	-	Contains m - number of selected rows
PLØT6	-	Unused
DUMPL8(1)	-	NØCASE
DUMPL8(2-30)	-	Unused

The data which is missing in the above list will be supplied via data input to the stand alone PLØT8 program.

DATA RECORD

TIME	-	current time
L_1^j	-	Selector No. 1
L_2^j	-	Selector No. 2
L_3^j	-	Selector No. 3
⋮		
L_m^j	-	Selector No. m

A data record is m + 1 words long where $1 \leq m \leq 72$. These records are written in the same way as discussed in Appendices A-E of the UFSSP Users Manual, [1].

D. ERROR PROCESSING

1. General

The program attempts to find all input data card errors during input processing that would create havoc with the program logic. The remainder of the checks will ensure that the correct loads history tape has been mounted and that the physical model it represents is compatible with the input card data. The program will complete the checking of the input data cards until every error has been found. The detection of any error listed below, however, will terminate the job so that no calculations will be performed.

2. List of Errors with Message Printed

ERROR

1 A check is made to see if Q/3 from the first card of the LTMP loads transformation data is = to NJTS from the body dependent header record of the UFSSP history tape. Message:

1 - LØADS TRANSFORMATION Q IS NØT CØMPATIBLE WITH NJTS

2 There is no structures record for flexible body j' (as found via NJPRIM(NOBOD)) on the loads history tape. This means that body j has 0 flexible DOF. Message:

2 - NØ STRUCTURES DATA RECØRD ØN UFSSP HISTØRY TAPE FØR BØDY JPRIME=____

3 A check is made to make sure the case no on the UFSSP history tape is = to HISCSE. Message:

3 - HISCSE IS NØT EQUAL TØ UFSSP HISTØRY TAPE CASE NØ. LØADS CASE____

4 The count m of the number of rows selected from the B^{j}_{MQ} matrix via the MSELEC array is > 72 or it is greater than M, the number of rows specified in the first card of the loads transformation data. Message:

4 - TØØ MANY RØWS SELECTED FRØM LØADS TRANSFØRMATIØN MATRIX

5 Each from-to pair in MSELEC and STIMn arrays are checked to make sure that the "FRØM" field is ≤ "TØ" field. Message:

5 - FRØM FIELD IS GREATER THAN THE TØ FIELD. ARRAY______ ENTRY______

6 Each "FRØM" entry in the MSELEC and STIMn arrays are checked to make sure that the current "FROM" entry is > than the previous one. Message:

6 - ENTRIES ARE ØUT ØF ØRDER IN ARRAY______

7 NØBØD is checked to make sure it is in the range 1 to NB. NB is obtained from the first record on loads history tape. Message:

7 - NØBØD IS NØT BETWEEN 1 and NB

8 NØBØD is checked to make sure that NJPRIM(NØBØD) specifies a non-zero j'. Message:

8 - NØBØD SPECIFIES A NØNFLEXIBLE BØDY

9 INPTRN is checked to be = 5 indicating loads transformation data is coming via cards or = 25 indicating it is to come in via a disk or tape file - TAPE25. Message:

9 - INPTRN SPECIFIES AN ERRØNEØUS INPUT DEVICE

VI. SAMPLE CASE

This first sample case is presented to illustrate how the required input data is to be entered plus the format of the program output.

A. PHYSICAL DESCRIPTION OF THE CASE

Figure 1 presents a schematic of the model chosen to demonstrate the operation of the program for a simplified configuration. The model chosen for simulation is that of a rigid central body with two identical flexible beams cantilevered diametrically on the perimeter of the central body. Thus, the model consists of three bodies, one rigid and two flexible.

Since the flexible bodies are identical, a single structural dynamics model is formulated consisting of a ten-foot long beam with mass concentrated at six mass points. Figure 2 depicts the uniform beam model. Physical characteristics of the beam are as follows:

$$\begin{aligned} \text{length} &= 120 \text{ in} \\ \text{mass/length} &= 0.01 \text{ lb.sec}^2/\text{in}^2 \\ EI_{yy} &= 6.66 \times 10^6 \text{ lb.in}^2 \\ EI_{zz} &= 1.48 \times 10^7 \text{ lb.in}^2 \end{aligned}$$

(The above values for EI_{yy} and EI_{zz} have been chosen to produce a first cantilever bending mode in the x-z plane at a frequency of approximately 1 Hz and a first cantilever bending mode in the x-y plane at a frequency of approximately 1.5 Hz.) As seen in Figure 2, the structural dynamics model consists of 9 joints and 7 uniform, massless beam members. The total mass of the beam is lumped at joints 2 through 7. Joint 1 is fully constrained while joint 8 represents the free end of the cantilever beam model. Joint 9 is a fictious joint needed by the structural dynamics program to define the three-dimensional geometry of the structure; like joint 1, it is fully constrained.

The model is initially stationary in inertial space. At time equal to zero, a triangular force pulse is applied to the center of mass of Body 1, directed along the $\underline{e}_3^1$ axis (t_o = 0 for $F_3^{1P}(t)$). In addition, at time equal to 2 seconds, a triangular force pulse is applied to the Body 1 mass center directed along the $\underline{e}_2^1$ axis (t_o = 2 for $F_2^{1P}(t)$).

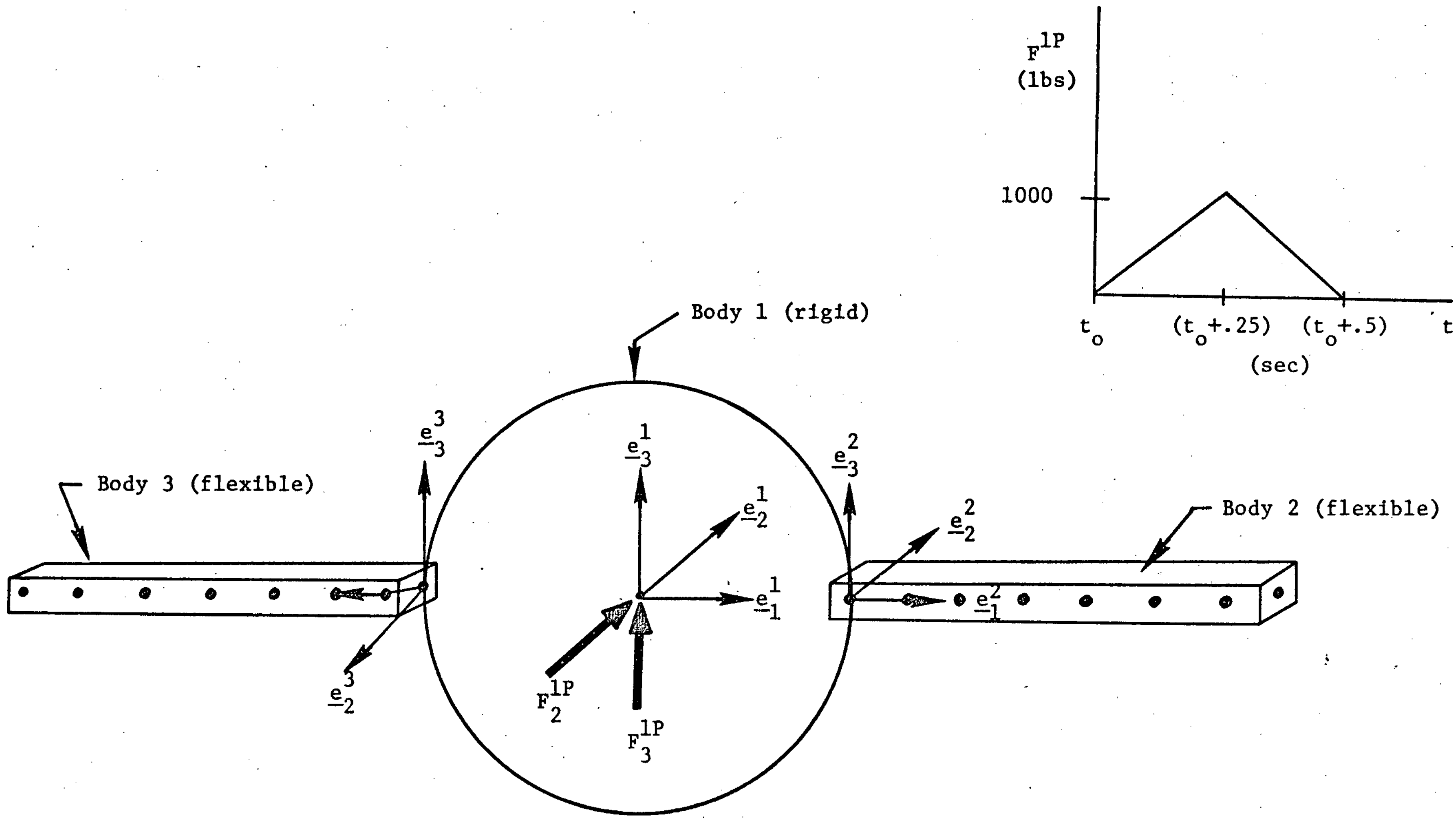


Figure 1. Schematic of Model for Test Case

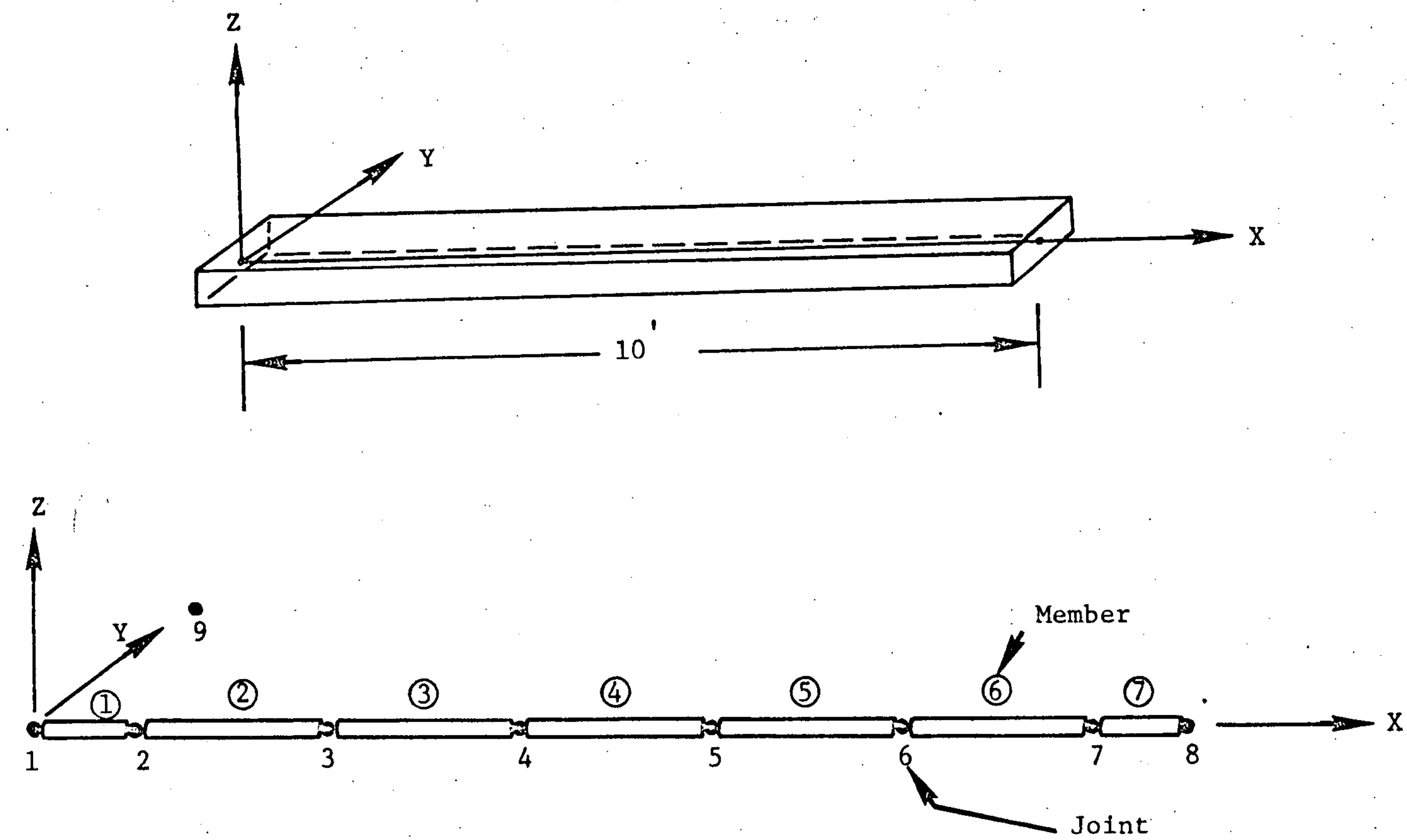


Figure 2. Flexible Beam Model

The basic objective of this test case is the determination of the interconnection loads between the bodies throughout the time history of this simulated thrusting sequence. These loads are computed in two ways, thus affording an internal check on the accuracy of the results. In the first calculation, the interconnection loads are computed by the UFSS Program itself; in the second calculation, the interconnection loads are computed by the LOAD Program as being equal to the internal loads acting on member 1 at its connection with joint 1 (see Figure 2).

B. DESCRIPTION OF THE UFSSP Run

Since the LØAD Program calculates internal loads via information obtained from a UFSSP history tape, it is first necessary to generate a time history simulation. The following pages contain the Namelist load sheets required for this sample case. Since most of the input data is the same as that described in the despin test case contained in the UFSSP Users Manual, it will not be described in detail here. The only basic differences lie in the tabular description of the applied forces. The entry ICALCF(1) = 1 indicates that prescribed disturbances are applied to Body 1. ITABN1(1,3) = 1 and ITABN1(1,2) = 2 further indicate that Body 1 is acted upon by a prescribed force whose third component is specified by the first interpolation table pair and whose second component is specified by the second interpolation table pair.

Figure 3 presents the standard UFSS print out of a typical time point (2.5 seconds). The interconnect force and torque values are given in units of lb and ft-lb respectively. Their components are along the $\underline{e}_\alpha^2$ body-fixed axes for Body 2 and along the $\underline{e}_\alpha^3$ body-fixed axes for Body 3.

Figures 4 and 5 present plots of the Body 2 interconnection forces and torques respectively. Note that F_3^{21} and T_2^{21} are due to the applied force F_3^{1P} while the remaining interconnection forces and torques arise from the applied force F_2^{1P}. The values for F_1^{21} are very small ($\simeq 10^{-9}$) as they should be from symmetry considerations. The values for T_1^{21} are small and arise purely through the flexible deformations of the beam.

Date ____________ Page 1 of 3

COMPUTATION AND DATA REDUCTION CENTER

Name ____________ Priority ____________

Problem No. ____________

NAMELIST INPUT FORM

Keypunched by ____________

No. of Cards ____________ Verified by ____________

TITLE: COMMENTS

```
LOAD  ① TEST ① CASE
LOAD  ① TEST ① CASE
P $CASEDS
ICASE = 400,
NB = 3,
LIMB(2) = 1, 1,
IBØDT = 0, 1, 1,
IRDØF = 6, 0, 0,
IFDØF = 0, 2, 2,
IØRBIT = -1,
IRDIS(15) = 1,
TI = 0,
TF = 10,
DELTI = 0.025,
NPRINT = 50,
MDMTH = -2,
CFMASS = 12,
CFLNTH = 0.08333,
MØDTP = 400,
IMDFLB = 2, 3,
MØDSEL(1,2) = 1,2,
MØDSEL (1,3) = 1,2,
NØDSEL (1,2) = 8,
NØDSEL (1,3) = 8.
```

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Date

Name

Problem No.

No. of Cards

COMPUTATION AND DATA REDUCTION CENTER

NAMELIST INPUT FORM

1

Priority

Keypunched by

Verified by

2 TITLE: 80 COMMENTS

```
NHIST  = 2,
IHIST  = 1,
IPLØTS = 2,
ICPLTV = 1, 5, 110, 8, 4, 109, 6, 7, 51, 52, 53, 3, 81, 82, 83,
LØAD   = 1,
INPMØD = 25,
$END

$INITCD
$END

$DYNAM
MASS =  1925, 14.4, 14.4,
CINE01 = 4810, 3*0, 4810, 3*0, 4810,
CINE02 = 1.0, 3*0, 477, 3*0, 477,
CINE03 = 1.0, 3*0, 477, 3*0, 477,
LIJ(1,2) = 2.5,
DLJI(1,2) = -5,
LIJ (1,3) = -2.5,
DLJI(1,3) = -5,
THETJØ(3,3) = 3.1415927,
VDMP02(1,1) = 0.0435,
VDMP02(2,2) = 0.0652,
VDMP03 (1,1) = 0.0435.
```

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Date ____________ Page 3 of 3

COMPUTATION AND DATA REDUCTION CENTER

Name ____________ Priority ____________

Problem No. ____________

NAMELIST INPUT FORM

Keypunched by ____________

No. of Cards ____________

1

Verified by ____________

TITLE: 2 ... 80 COMMENTS

```
  VDMP03(2,2) = 0.0652,
  $END

P $TABLES
  ICALCF(1) = 1,
  ITABN1(1,3) = 1,
  ITABN1(1,2) = 2,
  TBIN01 = 0.5, 0, 0.25, 0.5,
  TBDP01 = 0, 0, 1000, 0,
  TBIN02 = 2.5, 0, 2, 2.25, 2.5,
  TBDP02 = 0, 0, 0, 1000, 0,
$ END

P $DISTUR
  $END
P $ØRBITD
  $END
P $CØNINT
  $END
  HEAD1
  HEAD2
  $CASEDS
  ICASE = -1
  $END
```

SYSTEMS 2554 REV. 8-65

```
LOAD TEST CASE                                                                  CASE NO      400 PAGE   5

                                              BODY    1

       TIME              ORBIT NO          ORBIT ANGLE          SUN VECTOR             R1                 DET
    2.50000E+00              0             0.                  -7.08189E-15       -1.14867E-12       8.76171E+20
                                                                1.27770E-07        3.20384E-02
                                                               -1.00000E+00        2.88239E-01

      R1-DOT              OMEGA-1                                            AIR MATRIX
    1.06477E-11        -1.64912E-06       I    J             1                   2                   3
    1.27604E-01        -3.58041E-14       1              1.00000E+00       -4.71860E-15         7.08189E-15
    1.27966E-01        -3.33225E-14       2              4.71860E-15        1.00000E+00        -1.27770E-07
                                          3             -7.08189E-15        1.27770E-07         1.00000E+00

                                                                ORTHOGONALITY CHECK =   6.63829E-13
CHI=   1.00000E+00   KAPPA= -6.38851E-08     -3.54095E-15      -2.35930E-15

                                              BODY    2

   THETA          THETA-DOT            Q               Q-DOT                  DEFORMATION  I= NODE NO
 0.               0.             -2.37050E-02    3.16105E-02    I   J        1              2              3
 0.               0.             -1.62313E-02    1.50453E-01    1        2.60925E-16   -8.60052E-03   -1.25606E-02
 0.               0.

   INTERCONNECT-F      INTERCONNECT-T
    1.34644E-09         1.58786E-02
    3.87862E+00        -2.00619E+01
    2.76538E+00         2.81381E+01

                                              BODY    3

   THETA          THETA-DOT            Q               Q-DOT                  DEFORMATION  I= NODE NO
 0.               0.             -2.37050E-02    3.16105E-02    I   J        1              2              3
 0.               0.              1.62313E-02   -1.50453E-01    1       -2.70629E-18    8.60052E-03   -1.25606E-02
 0.               0.

   INTERCONNECT-F      INTERCONNECT-T
    1.34658E-09        -1.58786E-02
   -3.87862E+00        -2.00619E+01
    2.76538E+00        -2.81381E+01
```

Figure 3. Typical UFSS Time Print for Thruster Test Case

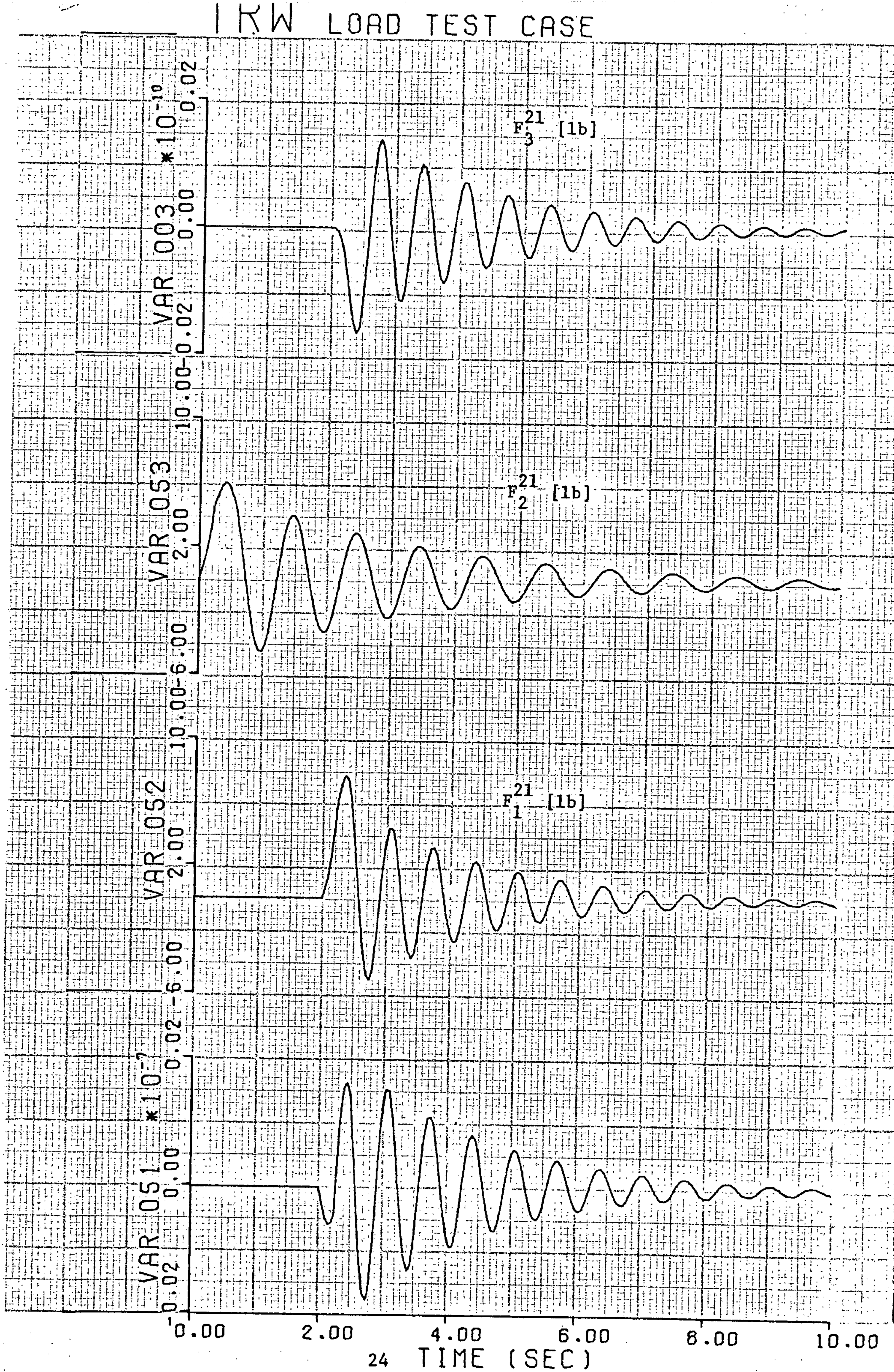


Figure 4. Body 2 Interconnection Forces (UFSSP)

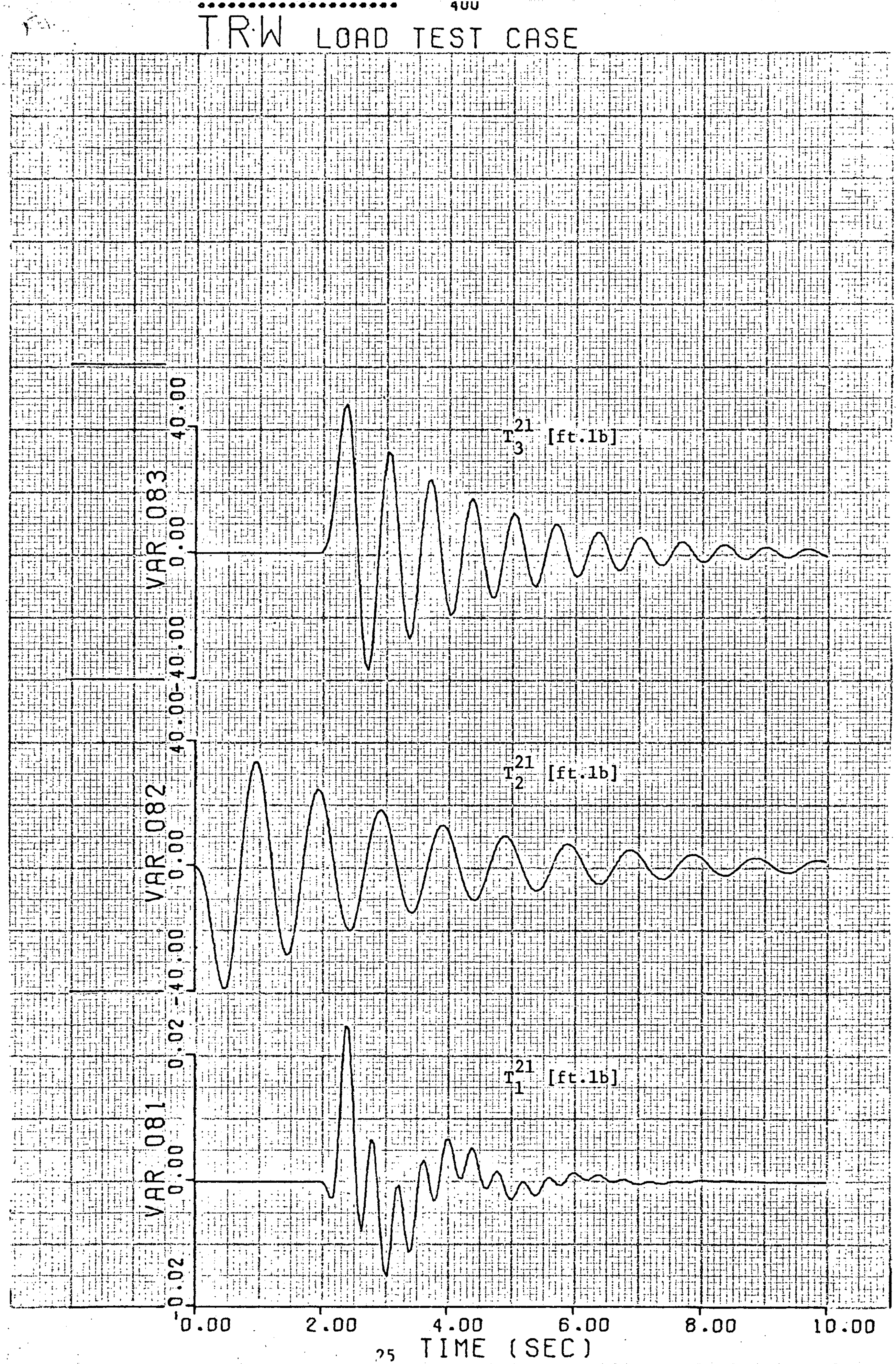


Figure 5. Body 2 Interconnection Torques (UFSSP)

C. DESCRIPTION OF THE LOAD RUN

For this test case the member forces at the start of member 1 are calculated via the appropriate LTM and Equation (1) for Body 2. Since Joint 1 has zero mass, these member forces should correspond to the interconnection forces and torques as calculated in the UFSS run described in B. above. This present section will discuss details of the LØAD run only; for details regarding definition of the internal loads and the LTM itself, the user is referred to Appendix A.

The Namelist input data set for this run is as follows:

```
THRUSTER LØAD TEST CASE
$LØAD
NØCASE  =  002,
NØBØD   =  2,
INPTRN  =  25,
MSELEC (1,1)  =  1,6,
HISCSE  =  400,
STIMO1(1)  =  0,10,1,
INPRNT  =  1,
$END
```

The NØCASE entry merely serves to identify the run. The "NØBØD = 2" entry indicates that internal loads are to be computed for Body 2, while the INPTRN entry specifies that the loads transformation matrix is to be input via a disk file. The MSELEC entry indicates that rows one through six of the LTM are to read into core for calculation, while the "HISCSE = 400" entry is set to match the "ICASE = 400" entry of the UFSS run used to supply input data; this correspondence assures that the correct UFSS history tape is read.

The entry "STIMO1(1) = 0,10,1" indicates that loads are to be computed for every time point on the UFSS history tape (recall that the UFSS run started at time equal to zero and ended at time equal to ten seconds). Finally, the "INPRNT = 1" entry specifies that the input card data set should be printed.

Figure 6 presents the standard print out of the input card data set. The print out is self-explanatory.

Figure 7 presents the standard output print of the LOAD Program. The correspondence between the load positions (rows of the LTM) and the interconnection forces calculated by the UFSS Program are as follows: (See Appendix A)

Load Position	UFSS Quantity
1	F_1^{21}
2	F_2^{21}
3	F_3^{21}
4	T_1^{21}
5	T_2^{21}
6	T_3^{21}

Thus, for example, Figure 7 reveals that F_3^{21} attains its maximum value of 5.97228 lb at four seconds into the run while attaining its minimum value of -4.591991 lb at 0.95 seconds into the run. All of the maxima and minima presented in Figure 7 can readily be verified by inspection of the plots for the member loads presented in Figure 8 (these plots are obtained by using the TRW stand-alone program AC041, with the LOAD history tape as input data). It should be noted here that the LTM was produced by the TRW program "LTMP" which -- like the TRW program, "SMAP", used to generate the structures data for the test case -- accepts only the units of lb, inch and second. Thus, all member loads corresponding to moments are output in units of lb-in by the LOAD Program. Finally, the following comparison of load values, as computed by the UFSS Program and the LOAD Program, are presented for a typical time point (2.5 seconds): (Units for moments are lb.in)

	UFSSP	LOAD
F_1^{21}	1.34644×10^{-9}	1.346442×10^{-9}
F_2^{21}	3.87862	3.878621
F_3^{21}	2.76538	2.765376
T_1^{21}	1.9054×10^{-1}	0
T_2^{21}	-2.4074×10^{2}	-2.407526×10^{2}
T_3^{21}	3.3765×10^{2}	3.376713×10^{2}

It should be noted that the value of T_1^{21} as predicted by the LOAD Program is identically zero. This computation is inherent to the geometry of the beam; since all mass points lie on the $\underline{e}_1^2$ axis, there is no moment arm to allow either applied or d'Alembert forces to produce a moment about the $\underline{e}_1^2$ axis.

It should be noted that care must be exercised when computing internal loads for a rapidly spinning flexible body. For the case of the model shown in Figure 1, computation of internal loads for a steady spin about the $\underline{e}_3^1$ axis will yield incorrect results for the member moments. These moments contain contributions due to the product of the centrifugal d'Alembert force and the instantaneous flexible deformations in the $\underline{e}_2^1$ and $\underline{e}_3^1$ directions at each joint. Since the load transformation matrix B_{MQ} used in Equation (1) is a constant matrix, there is no way that these moments can be included. Calculations for the member forces are correct.

The calculations of the interconnection forces and moments as performed within the UFSSP simulation run are correct for any motion of the model. Therefore, it is always advisable that these UFSSP values be compared to the root member forces computed by the LØAD Program in order that such spin effects may be identified and, if necessary, added to the computed member forces.

```
THRUSTER LOAD TEST CASE                    CASE NO.     2     BODY     2                PAGE    2

$LOAD

INPTRN = 25

HISCSE =    400

                    ROW SELECTOR FROM LOADS TRANSFORMATION FILE

MSELEC =
       FROM  1 TO  6 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0
       FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0
       FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0
       FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0
       FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0
       FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0
       FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0
       FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0 FROM  0 TO  0
       FROM  0 TO  0 FROM  0 TO  0

                    TIME HISTORY INTERVALS

STIM   =
       FROM  0.              TO  1.000000E+01 EVERY    1
       FROM -1.000000E+00 TO  0.              EVERY    0
       FROM -1.000000E+00 TO  0.              EVERY    0
       FROM -1.000000E+00 TO  0.              EVERY    0
       FROM -1.000000E+00 TO  0.              EVERY    0
       FROM -1.000000E+00 TO  0.              EVERY    0
       FROM -1.000000E+00 TO  0.              EVERY    0
       FROM -1.000000E+00 TO  0.              EVERY    0
       FROM -1.000000E+00 TO  0.              EVERY    0
       FROM -1.000000E+00 TO  0.              EVERY    0

$END
```

Figure 6. Standard Print-out of LOAD Input Data

```
THRUSTER LOAD TEST CASE                          CASE NO.    2     BODY     2                 PAGE    3

        MINIMUM LOAD (POSITION  1) = -1.804106E-09        TMIN  =       2.750000

        LOAD VECTOR FOR MINIMUM

POS        VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE
  1 -1.804106E-09      2 -5.196968E+00      3 -7.246133E-01      4  0.                     5  6.308456E+01      6 -4.524460E+02

        MAXIMUM.LOAD (POSITION  1) =  1.630375E-09        TMAX  =       2.450000

        LOAD VECTOR FOR MAXIMUM

POS        VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE
  1  1.630375E-09      2  6.170596E+00      3  2.900168E+00      4  0.                     5 -2.524876E+02      6  4.973225E+02

        MINIMUM LOAD (POSITION  2) = -5.196968E+00        TMIN  =       2.750000

        LOAD VECTOR FOR MINIMUM

POS        VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE
  1 -1.804106E-09      2 -5.196968E+00      3 -7.246133E-01      4  0.                     5  6.308456E+01      6 -4.524460E+02

        MAXIMUM.LOAD (POSITION  2) =  7.677600E+00        TMAX  =       2.350000

        LOAD VECTOR FOR MAXIMUM

POS        VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE
  1  1.130080E-09      2  7.677600E+00      3  2.300101E+00      4  0.                     5 -2.002459E+02      6  5.487472E+02

        MINIMUM LOAD (POSITION  3) = -4.591991E+00        TMIN  =        .950000

        LOAD VECTOR FOR MINIMUM

POS        VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE      POS       VALUE
  1  7.325532E-14      2 -4.141460E-10      3 -4.591991E+00      4  0.                     5  3.997770E+02      6 -3.629366E-08
```

Figure 7.   LOAD Standard Output Print

```
THRUSTER LCAD TEST CASE                          CASE NO.    2    BODY    2                        PAGE    4

        MAXIMUM.LOAD (POSITION  3) =  5.972280E+00          TMAX  =        .400000

        LOAD VECTOR FOR MAXIMUM

POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE
  1 -4.827097E-14       2  3.998445E-11       3  5.972280E+00       4  0.                 5 -4.401700E+02       6  3.420046E-09

        MINIMUM LOAD (POSITION  4) =  0.                    TMIN  =       0.000000

        LOAD VECTOR FOR MINIMUM

POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE
  1  0.                 2  0.                 3  0.                 4  0.                 5  0.                 6  0.

        MAXIMUM.LOAD (POSITION  4) =  0.                    TMAX  =       0.000000

        LOAD VECTOR FOR MAXIMUM

POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE
  1  0.                 2  0.                 3  0.                 4  0.                 5  0.                 6  0.

        MINIMUM LOAD (POSITION  5) = -4.741888E+02          TMIN  =        .450000

        LOAD VECTOR FOR MINIMUM

POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE
  1 -7.070909E-14       2  8.006723E-11       3  5.904873E+00       4  0.                 5 -4.741888E+02       6  6.962012E-09

        MAXIMUM.LOAD (POSITION  5) =  3.997770E+02          TMAX  =        .950000

        LOAD VECTOR FOR MAXIMUM

POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE        POS      VALUE
  1  7.325532E-14       2 -4.141460E-10       3 -4.591991E+00       4  0.                 5  3.997770E+02       6 -3.629366E-08
```

Figure 7. LOAD Standard Output Print (continued)

```
THRUSTER LCAD TEST CASE                                   CASE NO.      2      BODY      2                        PAGE    5

         MINIMUM LOAD (POSITION   6) = -4.524460E+02         TMIN   =        2.750000

         LOAD VECTOR FOR MINIMUM
POS        VALUE       POS       VALUE       POS       VALUE       POS       VALUE       POS       VALUE       POS       VALUE
  1 -1.804106E-09     2 -5.196968E+00    3 -7.246133E-01    4  0.                          5  6.308456E+01    6 -4.524460E+02

         MAXIMUM.LOAD (POSITION   6) =  5.677655E+02         TMAX   =        2.400000

         LOAD VECTOR FOR MAXIMUM
POS        VALUE       POS       VALUE       POS       VALUE       POS       VALUE       POS       VALUE       POS       VALUE
  1  1.558585E-09     2  7.437891E+00    3  2.742842E+00    4  0.                          5 -2.387908E+02    6  5.677655E+02
```


Figure 7. LOAD Standard Output Print (continued)

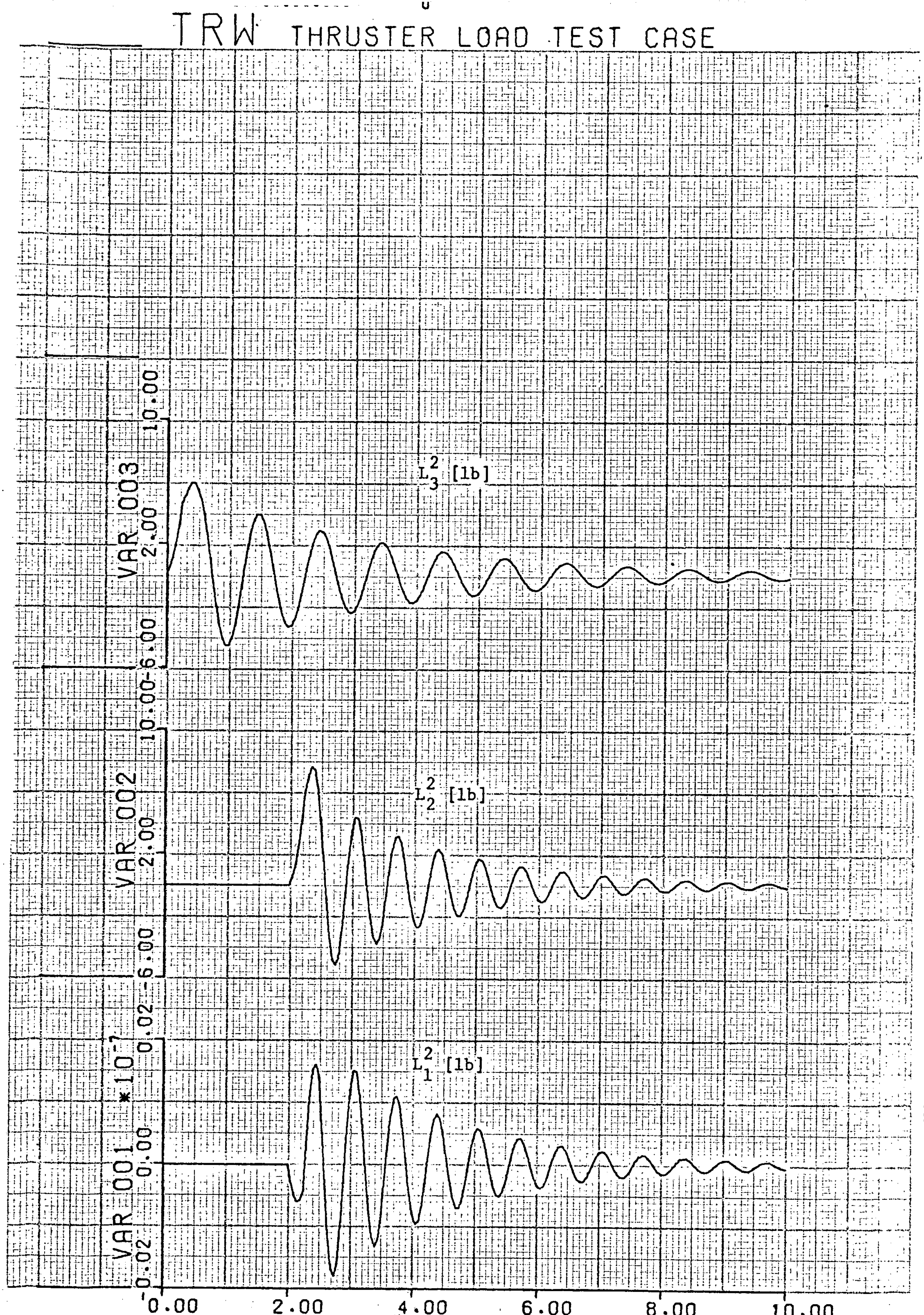


Figure 8. Body 2 Internal Loads in Member 1 at Joint 1

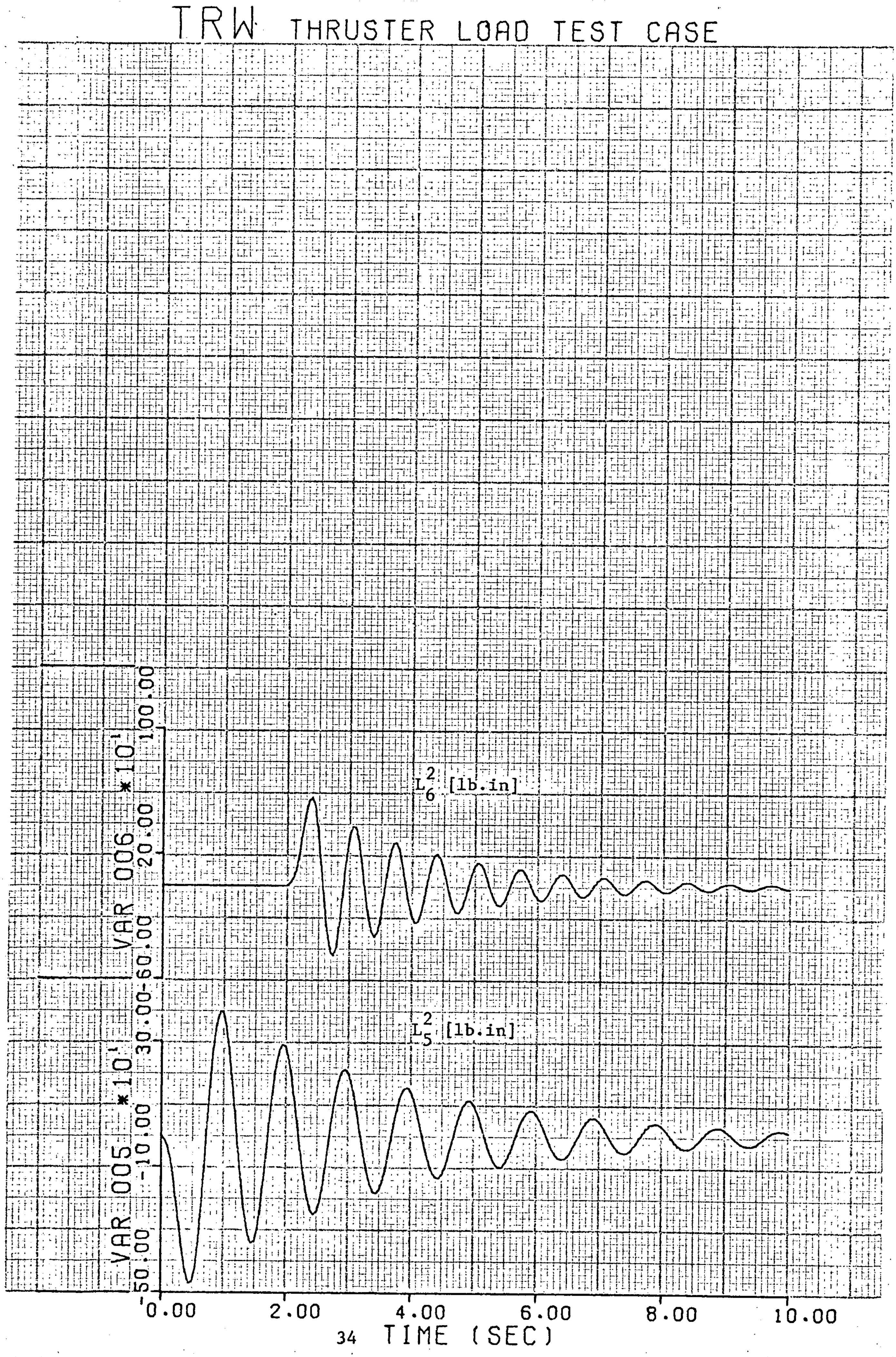


Figure 8. Body 2 Internal Loads in Member 1 at Joint 1 (continued)

PART II. OPERATION MANUAL

VII. SOFTWARE/HARDWARE REQUIREMENTS

CDC 6500

This program runs under the TRW/TSS system and requires 41,000 words of core and 3 files. These files may be on disk or tape.

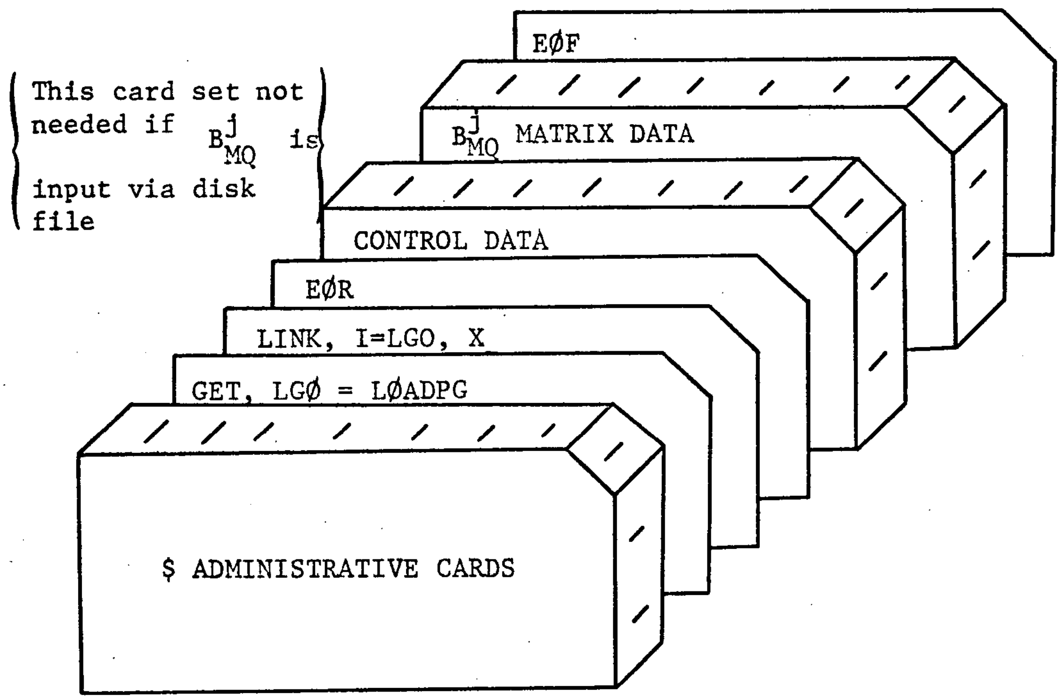
UNIVAC 1108

This program runs under the exec 8 system and requires 40,000 words of core plus 3 files. These files can be on drum or tape.

VIII. OVERALL DECK SETUP

CDC 6500

The following diagram assumes that the program, in relocatable form, is stored on disk under file name LØADPG and the B^j_{MQ} matrix is to be input from cards.



UNIVAC 1108

(To be supplied by MSFC programming staff.)

IX. TAPE/DISK/DRUM USAGE

Program Symbol	CDC File No.	UNIVAC File No.	Tape Usage	Mode
INPTRN	25	25	B^j_{MQ} Matrix Card File	BCD
10	10	10	UFSSP History Tape	BINARY
8	8	8	Loads History Tape for Plotting	BINARY
5	5	5	Input Card Set	BCD
6	6	6	Print Data Set	BCD

X. PROGRAM LOAD MAP

CDC 6500

```
LOAD MAP.  PROGRAM  LOAD        12/12/72. 22.12.25. PAGE    1

LOAD OPTIONS -  X

FL REQUIRED TO LOAD   27700
FL REQUIRED TO RUN   117400
INITIAL TRANSFER TO LOAD        -       101


BLOCK ASSIGNMENTS.

BLOCK       ADDRESS   LENGTH    FILE      DATE

LOAD          100      2731     LGO       12/12/72.
/BASIC/      3031      2433
INPTPR       5464       245     LGO       12/12/72.
ABC          5731       146     LGO       12/12/72.
ABFC         6077        71     LGO       12/12/72.
AEBC         6170       175     LGO       12/12/72.
AEBPC        6365       117     LGO       12/12/72.
CROSS        6504        41     LGO       12/12/72.
SCAL         6545        55     LGO       12/12/72.
CRCP         6622        42     LGO       12/12/72.
ENDFIL       6664        73     RUNLIB    *NO-DATE*
IFENDF       6757        32     RUNLIB    *NO-DATE*
INPUTB       7011       315     RUNLIB    01/16/72.
INPUTC       7326      1211     RUNLIB    04/06/72.
INPUTN      10537      1661     RUNLIB    08/11/71.
OUTPTB      12420       250     RUNLIB    06/02/71.
OUTPTC      12670      1334     RUNLIB    04/06/72.
GETBA       14224        17     RUNLIB    *NO-DATE*
SIO$        14243       407     RUNLIB    04/06/72.
SYSTEM      14652      1214     RUNLIB    04/06/72.
SYSTEMC     16066        43     RUNLIB    11/26/72.
CPLCDD      16131        13     RUNLIB    05/28/71.
CPLCIO      16144       257     RUNLIB    09/19/72.
```

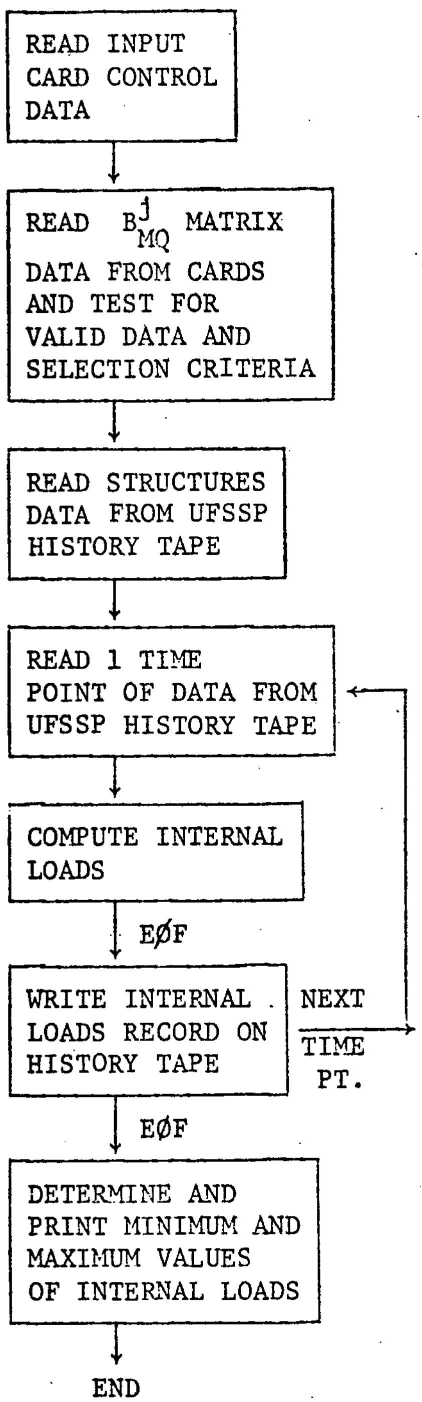
LCAD MAP. PRCGRAM LCAD 12/12/72. 22.12.25. PAGE 2
BLOCK ASSIGNMENTS.

BLCCK	ADDRESS	LENGTH	FILE	DATE
CPLSYS	16423	24	RUNLIB	10/10/71.
/FIOBUF$/	16447	14154		
/LFT/	32623	3445		
/TFST/	36270	1072		
/FICBLFR/	37362	230		
//	37612	57530		

UNIVAC 1108

(To be supplied by MSFC programming staff.)

XI. BLOCK DIAGRAM OF LOAD PROGRAM



Appendix A. Load Transformation Matrix Description

This appendix further defines and describes the flexible body structural dynamics model and the internal member loads within a structure modeled as a system of lumped-mass joints which are interconnected by weightless beam elements. The following discussion is mainly drawn from the user manual for the TRW developed LOAD TRANSFORMATION MATRIX PROGRAM (LTMP) -- the program used to generate the LTM for the sample case contained in Section VI of this document. For purposes of analysis, the structures admissible to the LTMP are grouped into the following five types:

1) Three-dimensional trusses,
2) Three-dimensional frames whose member cross sections have polar symmetry,
3) Two-dimensional frames (motion in XY plane of structure),
4) Two-dimensional grids (motion normal to XY plane of structure),
5) Three-dimensional frames whose member cross sections need not have polar symmetry.

For use with the UFSS and LOAD Programs, we will consider only structure type 5.

Typical of most structural dynamics programs, the following quantities describe the structure:

1) Coordinates of the joints,
2) Properties of the materials of which the structure is composed,
3) Geometric properties of the member elements,
4) Location of restraints.

The elastic properties for the elements are defined by the material properties. The material properties consist of Young's modulus of elasticity, Poisson's ratio, the shear modulus, and the coefficient of thermal expansion in each of two orthogonal directions (the local x and y axes of the element). The material density is also entered.

The geometric properties of a member element consist of the joint numbers at the start and end of the member, the cross sectional area, the effective shear areas in the local y and z axes, the area moment of inertia about the local y and z axes, and the section torsional stiffness.

Two types of reference systems are used in the LTMP: right-handed, orthogonal, Cartesian coordinate systems for structure geometry, displacements, and forces; and a numbering convention to define the degrees of freedom in the structure.

Coordinate Reference Systems

Right-handed, orthogonal, Cartesian coordinate systems are used to describe the geometry of the structure, the joint displacements, and the member displacements and forces. The description of the structure requires two different coordinate systems. One is the overall system, termed the global coordinate system. The other is a coordinate system which is fixed to each element in the structure; these latter are called local coordinate systems.

Global Coordinate System

The global coordinate system is an arbitrarily selected coordinate system, usually positioned so the directions of the axes coincide with some of the major dimensions of the structure. Upper case letters are used when referring to the global coordinate system. The positive directions are denoted by X, Y, Z. (These directions coincide with the body-fixed axes $\underline{e}_1^j$, $\underline{e}_2^j$ and $\underline{e}_3^j$ used in the UFSS and LOAD Programs.) The global coordinate system is used to describe joint coordinates, joint deflections, and externally applied forces. The six possible displacement components (degrees of freedom), δ_{jX}, δ_{jY}, δ_{jZ}, θ_{jX}, θ_{jY}, θ_{jZ}, for the jth joint are defined in the global coordinate system as shown in Figure A.1. (These displacement components are identical to the joint modal deformations ϕ_1^{jN}, ϕ_2^{jN}, ϕ_3^{jN}, θ_1^{jN}, θ_2^{jN} and θ_3^{jN} for joint N of Body j as used in the UFSS and LOAD Programs.)

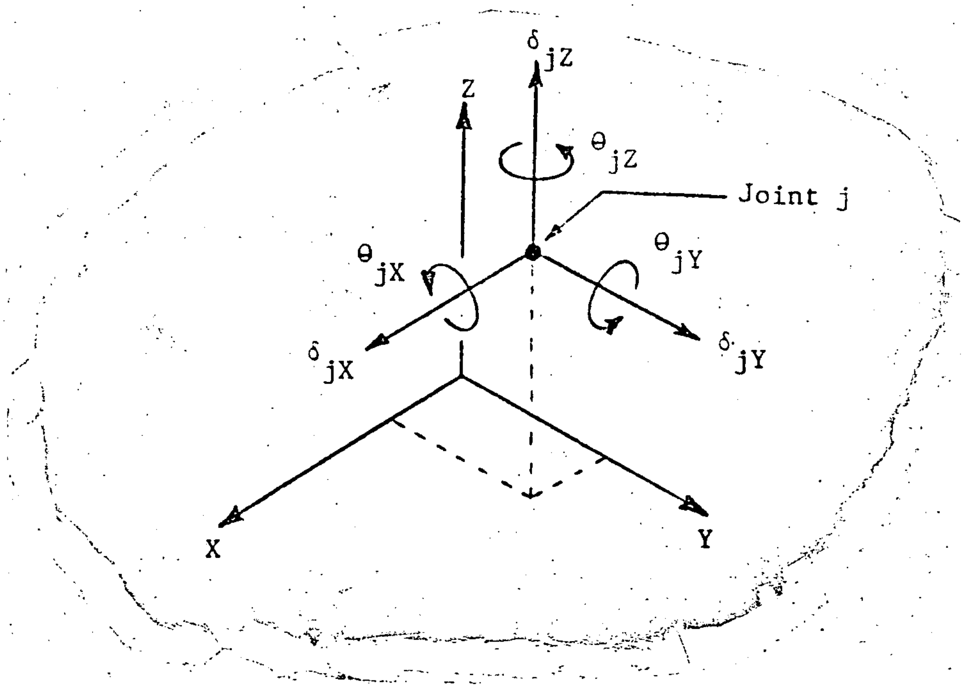


Figure A.1. Global Coordinate System

Reference System for Degrees of Freedom

A number is assigned to each degree of freedom in the structure, whether it is rigidly constrained or free to move. The degrees of freedom are numbered sequentially, starting at joint 1 and continuing to the last joint. Thus, for example, the degrees of freedom at joint 5 of a structure would be numbered as shown below.

δ_{jX} : 25

δ_{jY} : 26

δ_{jZ} : 27

θ_{jX} : 28

θ_{jY} : 29

θ_{jZ} : 30

Member Element

The idealized member elements used to represent a weightless beam or rod between two points in the structure are subject to the following assumptions:

1) All members are represented by a straight line which is attached to two joints of the structure. The straight line corresponds to the centroidal axis of the member.

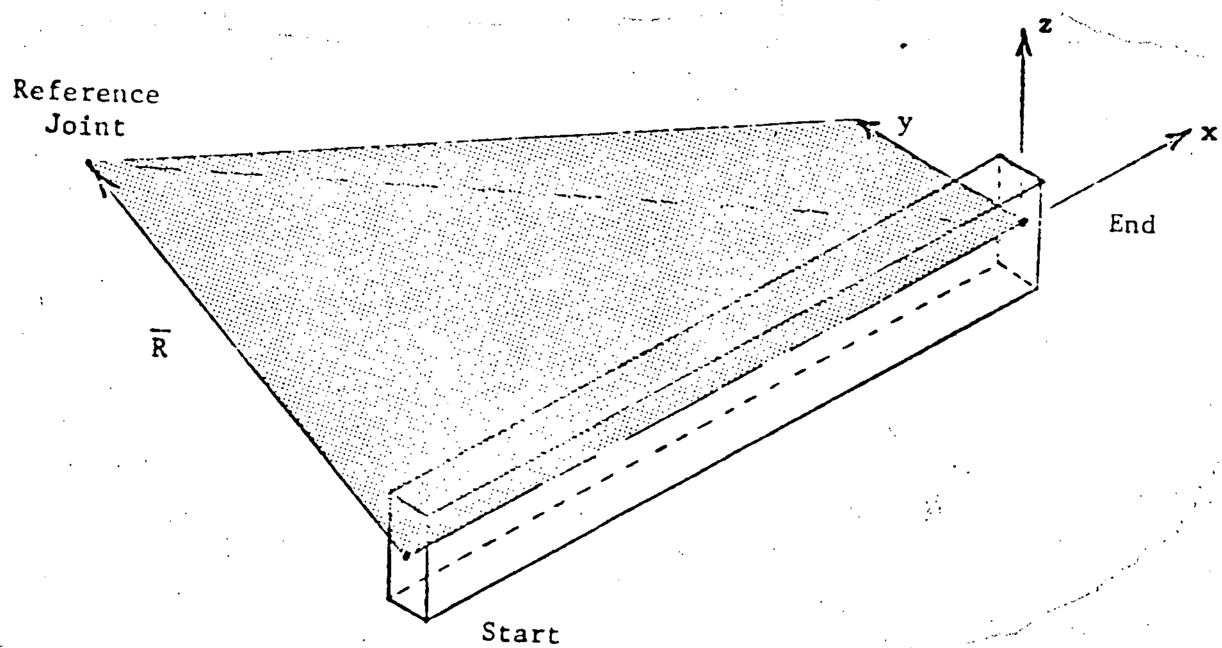


Figure A.2. Member Local Coordinate System for Type 5 Structure

2) All members have uniform cross sectional properties between the two end joints with the section properties defined about the principal axes of the cross section.

3) The local y and z axes are the principal axes of the cross section.

4) The shear center of the cross section coincides with the centroid of the section.

5) Axial forces act along the centroidal axis of the member.

6) The member's elemental stiffness matrix is formed using small deflection theory.

Since the member elements are interconnected at discrete points, the elemental stiffness matrix of the member represents the exact stiffness relationship between the two end joints.

Local Coordinate System

The position and orientation of a given member element in space is specified by the coordinates of the end joints and a linear transformation matrix relating the local member coordinate system to the global coordinate system. The local coordinate system is fixed to the member and is used to relate the stiffness properties, deflections, and forces of the member back to the global coordinate system. Lower case letters are used when referring to the local coordinate systems. The local x axis always extends in a positive direction from the start of the member (first joint specified) to the end of the member (second joint specified). The orientation of the y and z axes is determined as follows:

Type 5. A reference joint (specified by input data) is required to define the orientation of the y and z axes for the Type 5 structure. Let R be a vector from the first joint of the member to the reference joint (see Figure A.2). The local z axis is perpendicular to the plane formed by the member's local x axis and the vector $\bar{R}$. It is positive in the direction of the vector cross-product of the local x axis and $\bar{R}$ respectively. The local y axis is in the plane which is formed and in a direction which will form a right-handed, orthogonal, Cartesian coordinate system with the local x and z axes. Note that the reference joint must not be located on the local x axis. The reference joints must be an existing joint in the input data. If none of the actual joints in the structure can be used as a reference joint, an arbitrary

Type 5 (Cont'd)
reference joint with all degrees of freedom rigidly constrained can be specified without increasing the size of the stiffness matrix.

Member Displacements and Forces

Each member has twelve possible displacements defined in the local coordinate system. These displacements are obtained by transforming the joint displacements at the ends of the member from the global coordinate system to the local coordinate system of the member. A member displacement is positive in the positive direction of the local coordinate system.

The member forces are also defined in the local member coordinate system. Member forces are positive if they act in the positive direction of the member coordinate system. The twelve possible forces associated with a member of the structure are shown in Figure A.3. All forces shown are positive.

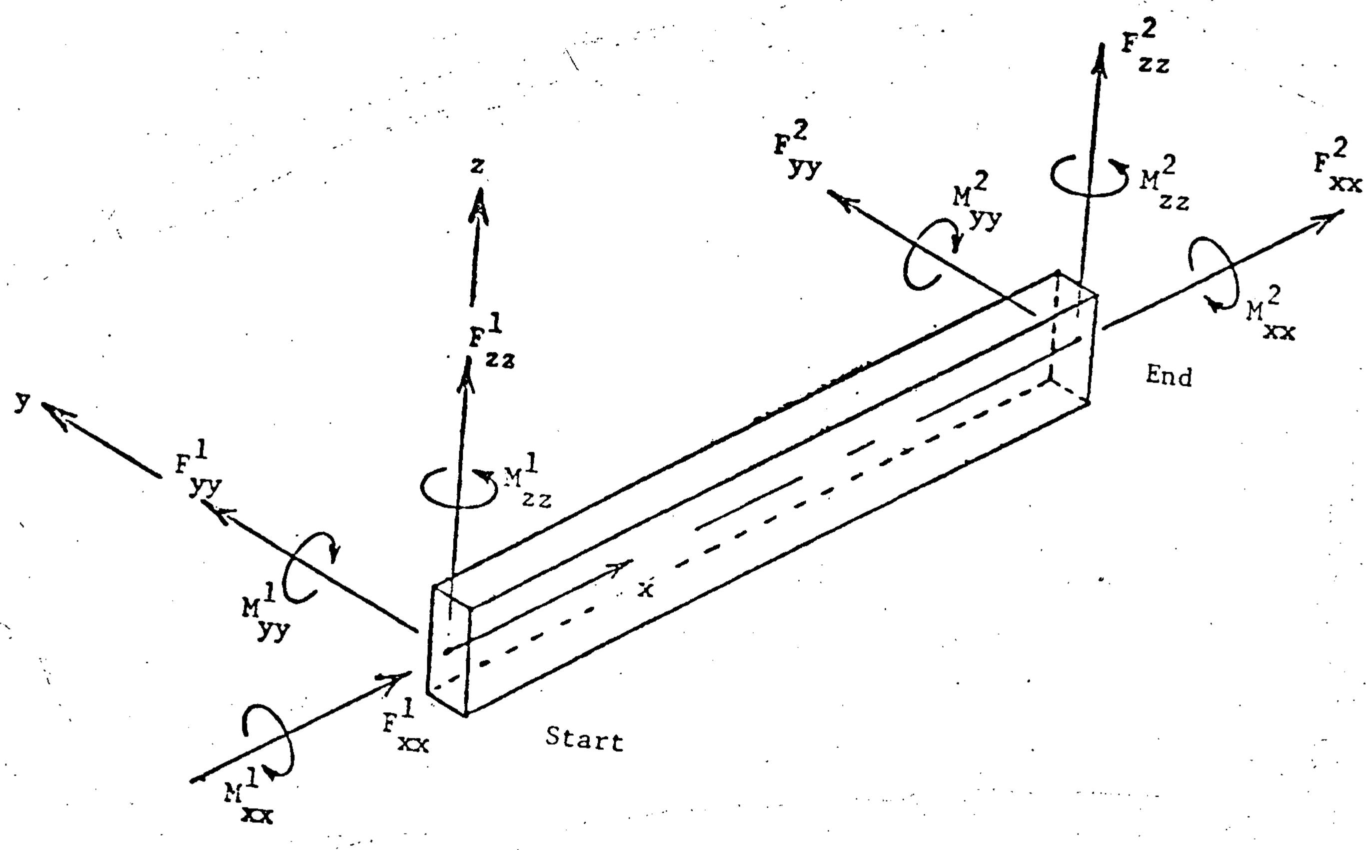


Figure A.3. Member Forces

Load Transformation Matrix Definition

As defined previously, each row of the LTM corresponds to a given member force. Thus, there can be a total of 12M member forces (internal loads) computed, where M is the total number of members within the structural dynamics model.

Let us now consider the structural model used in the test case of Section VI. The LTM generated for this structure is presented in Figure A.4. The first line of the card file indicates that the LTM contains 12 rows and 27 columns. The number of columns is completely determined by the model as being equal to three times the number of joints. However, the number of rows is arbitrary, being equal to the number of member forces (internal loads) selected by the user. For the present case, the load coefficients for the six member forces at the start of member 1 (i.e., at its connection with joint 1) comprise the elements of the first six rows of the LTM. The load coefficients for the six member forces at the start of member 5 (i.e., at its connection with joint 5) comprise the elements of the last six rows of the LTM.

It should be noted that columns 1, 2 and 3 (corresponding to external forces applied to joint 1) and columns 25, 26 and 27 (corresponding to external forces applied to joint 9) are identically zero due to the fact that these two joints are fully constrained. In addition, rows 4 and 10 (corresponding to axial moments within members 1 and 5) are identically zero due to the fact that all joint masses lie on the global X axis which corresponds to the local x axis for each member.

Through the MSELEC entry in the sample case, only the member forces in member 1 were calculated in the sample case run.

```
12 27
0.             0.             0.             -1.000000E+00  0.                               1
0.             -1.000000E+00  0.             0.             -1.000000E+00                    2
0.             0.             -1.000000E+00  0.             0.                               3
-1.000000E+00  0.             0.             -1.000000E+00  0.                               4
0.             -1.000000E+00  0.             0.             0.                               5
0.             0.                                                                            6
0.             0.             0.             0.             -1.000000E+00                    7
0.             0.             -1.000000E+00  0.             0.                               8
-1.000000E+00  0.             0.             -1.000000E+00  0.                               9
0.             -1.000000E+00  0.             0.             -1.000000E+00                    10
0.             0.             -1.000000E+00  0.             0.                               11
0.             0.                                                                            12
0.             0.             0.             0.             0.                               13
-1.000000E+00  0.             0.             -1.000000E+00  0.                               14
0.             -1.000000E+00  0.             0.             -1.000000E+00                    15
0.             0.             -1.000000E+00  0.             0.                               16
-1.000000E+00  0.             0.             -1.000000E+00  0.                               17
0.             0.                                                                            18
0.             0.             0.             0.             0.                               19
0.             0.             0.             0.             0.                               20
0.             0.             0.             0.             0.                               21
0.             0.             0.             0.             0.                               22
0.             0.             0.             0.             0.                               23
0.             0.                                                                            24
0.             0.             0.             0.             0.                               25
1.000000E+01   0.             0.             3.000000E+01   0.                               26
0.             5.000000E+01   0.             0.             7.000000E+01                     27
0.             0.             9.000000E+01   0.             0.                               28
1.100000E+02   0.             0.             1.200000E+02   0.                               29
0.             0.                                                                            30
0.             0.             0.             0.             -1.000000E+01                    31
0.             0.             -3.000000E+01  0.             0.                               32
-5.000000E+01  0.             0.             -7.000000E+01  0.                               33
0.             -9.000000E+01  0.             0.             -1.100000E+02                    34
0.             0.             -1.200000E+02  0.             0.                               35
0.             0.
0.             0.             0.             1.626303E-14   0.                               37
0.             5.421011E-14   0.             0.             8.673617E-14                     38
0.             0.             1.084202E-13   0.             0.                               39
-1.000000E+00  0.             0.             -1.000000E+00  0.                               40
0.             -1.000000E+00  0.             0.             0.                               41
```

Figure A.4. Load Transformation Matrix for Sample Case

C.	C.				42
0.	0.	0.	0.	-1.350031E-13	43
C.	0.	-1.3C7399E-12	C.	0.	44
-2.273737E-12	0.	C.	-5.456968E-12	0.	45
C.	-1.CCOCCOE+CC	C.	0.	-1.000CCOE+CO	46
0.	0.	-1.CCOOCCE+CO	0.	0.	47
0.	0.				48
C.	0.	0.	0.	0.	49
-4.334311E-13	C.	C.	-3.637979E-12	0.	50
0.	-9.777C68E-12	C.	0.	-1.864464E-11	51
C.	C.	-1.CCOOCCE+CO	0.	0.	52
-1.CCCOCCE+00	0.	C.	-1.COOOOCE+CC	0.	53
0.	0.				54
C.	0.	C.	0.	0.	55
C.	C.	C.	0.	0.	56
C.	0.	C.	0.	0.	57
C.	C.	0.	C.	0.	58
0.	0.	0.	C.	0.	59
0.	0.				60
C.	0.	0.	0.	0.	61
2.205525E-11	C.	0.	1.873559E-1C	0.	62
C.	4.893081E-1C	0.	C.	9.094947E-1C	63
C.	0.	2.COOOCOE+01	0.	0.	64
4.CCCCCOE+01	0.	C.	5.0CC00OE+C1	0.	65
0.	0.				66
C.	0.	0.	0.	-8.299139E-12	67
0.	0.	-7.275958E-11	0.	0.	68
-1.78261CE-10	C.	C.	-3.4197CCE-10	0.	69
C.	-2.CCOCCCE+C1	C.	C.	-4.000CCOE+01	7C
0.	0.	-5.CCCOCOE+01	0.	0.	71
C.	C.				72

Figure A.4. Load Transformation Matrix for Sample Case (continued)

REFERENCES

1. Ness, D. J., Hull, G. E. and Farrenkopf, R. L., "Unified Flexible Spacecraft Simulation Program (UFSSP) User's Manual", TRW No. 14938-6009-RU-00, December, 1972.

2. Ness, D. J., "Unified Flexible Spacecraft Simulation Program (UFSSP) Methodology Report", TRW No. 14938-6010-RU-00, December, 1972.